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14. ABSTRACT
This slide presentation summarizes the five-year results of natural attenuation treatability studies at 42 Air Force sites contaminated with fuel hydrocarbons. The main emphasis of the work described in this report was to evaluate the potential for naturally occurring degradation mechanisms to reduce dissolved benzene, ethylbenzene, toluene, and xylenes concentrations in groundwater to levels that are protective of human health and the environment.

15. SUBJECT TERMS
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Natural Attenuation of Fuel Hydrocarbons Performance and Costs Results from Multiple Air Force Demonstration Sites

Presented by

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Parsons

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Natural Attenuation Initiative

- **Document the effectiveness and promote the use of monitored natural attenuation (MNA) to cost-effectively achieve cleanup and closure of fuel spill sites at Air Force facilities.**
- ***Technical Protocol for Implementing Intrinsic Remediation with Long-Term Monitoring for Natural Attenuation of Fuel Contamination Dissolved in Groundwater*** **(AFCEE Technical Protocol, 1995).**
- **Currently, at least 44 states and all 10 USEPA regions will consider the use of MNA as a viable remedy for fuel-contaminated groundwater.**

The United States Environmental Protection Agency (USEPA, 1999) Office of Solid Waste and Emergency Response (OSWER) defines MNA as:

...the reliance on natural attenuation processes (within the context of a carefully controlled and monitored clean-up approach) to achieve site-specific remediation objectives within a time frame that is reasonable compared to that offered by other more active methods. The "natural attenuation processes" that are at work in such a remediation approach include a variety of physical, chemical, or biological processes that, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil and groundwater. These in-situ processes include biodegradation; dispersion; dilution; sorption; volatilization; radioactive decay; and chemical or biological stabilization, transformation, or destruction of contaminants.

42 sites with a wide variety of environmental and contaminant conditions were investigated, including:

- **Site locations ranging from Alaska to Florida;**
- **Depths to groundwater ranging from 0 to 48 feet below ground surface (bgs);**
- **Plume areas ranging from 0.3 to 60 acres, and plume lengths of 100 to 3,000 feet;**
- **Average groundwater temperatures ranging from 5.5 to 26.9 degrees Celsius (°C); and**
- **Soil types ranging from silty clay to coarse sand and gravel.**

Natural Attenuation Initiative Locations

Treatability Study Objectives

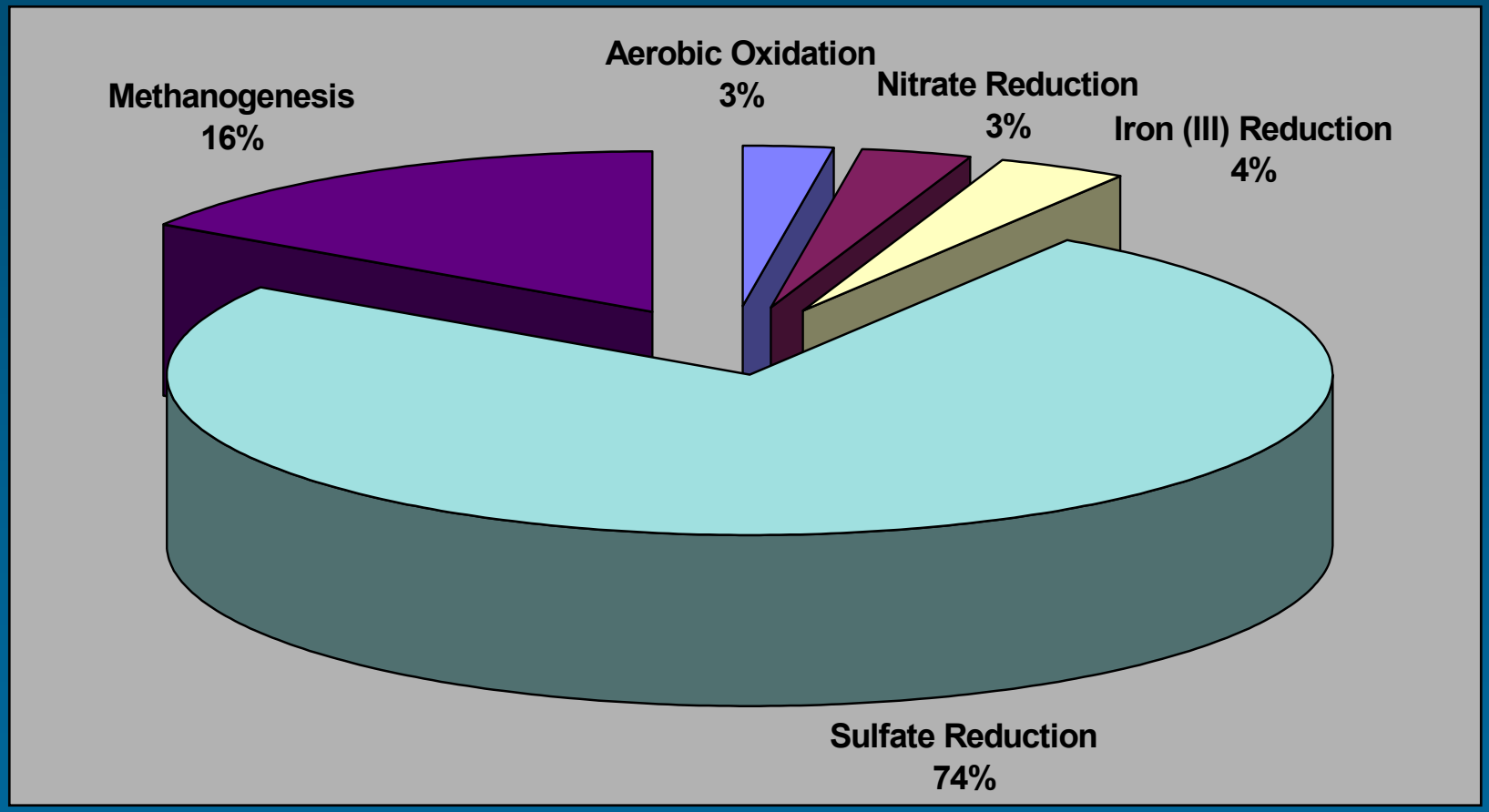
- Develop efficient site characterization techniques to accurately document natural attenuation and to reduce overall expenditures of time and money.
- Identify those biological processes most responsible for contaminant attenuation.
- Determine rates of contaminant destruction.
- Use groundwater flow and solute fate and transport models to predict the effects of natural attenuation, both alone and in combination with engineered remedial technologies, on the future migration and persistence of dissolved BTEX.

Drill Rig and Jet

Treatability Study Results

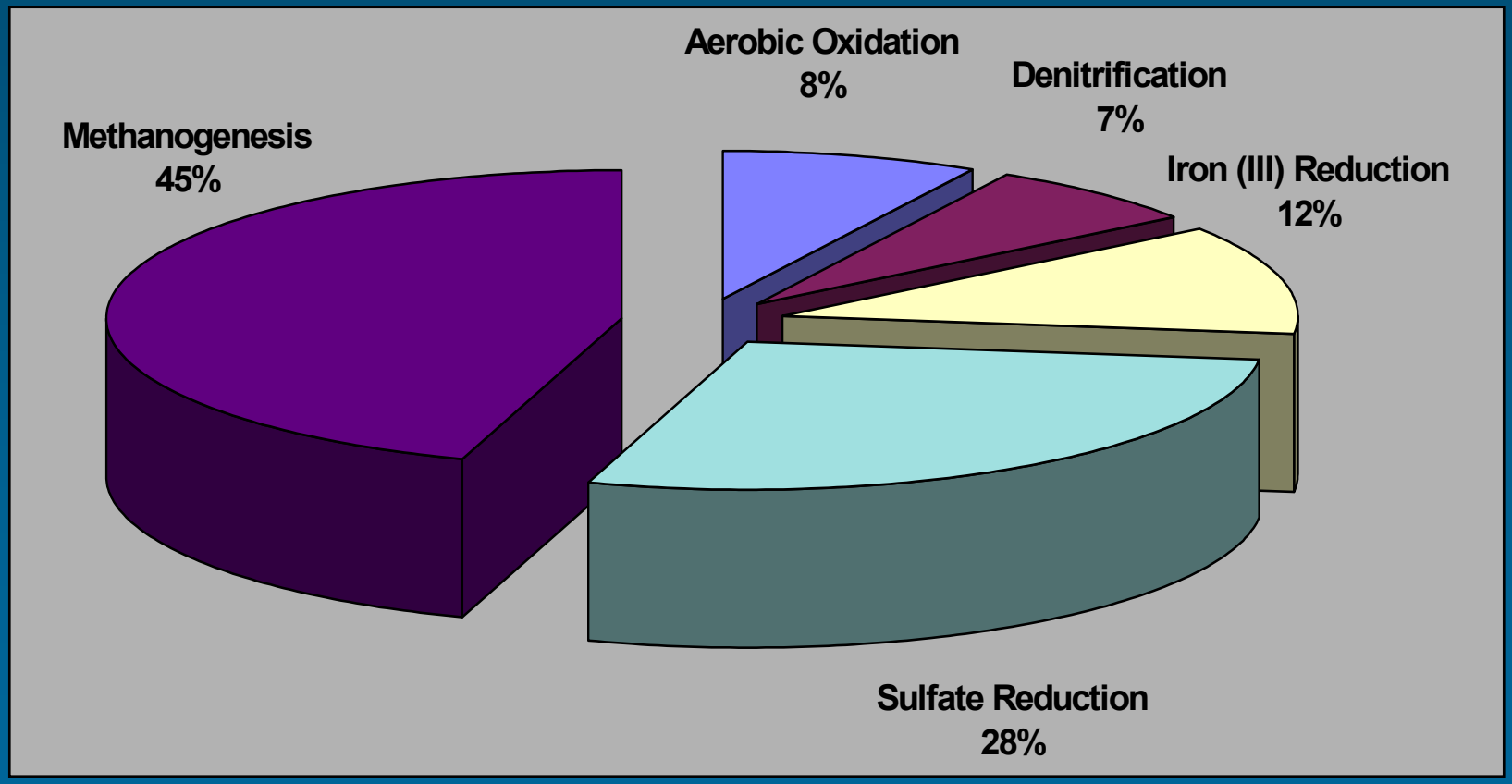
- **Dissolved BTEX compounds are undergoing natural attenuation (biodegradation) at all 42 Air Force test sites representing a broad range of environmental conditions.**
- **The majority of dissolved BTEX plumes were either stable or receding (historical data or model predictions).**
- **The average relative contribution of each primary biodegradation process to the total assimilative capacity of the groundwater system decreased in the following order: sulfate reduction, methanogenesis, iron reduction, denitrification, and aerobic oxidation.**

Average Relative Contribution of BTEX Biodegradation Processes in Site GW



Average Relative Contributions of BTEX Biodegradation Processes in Site GW

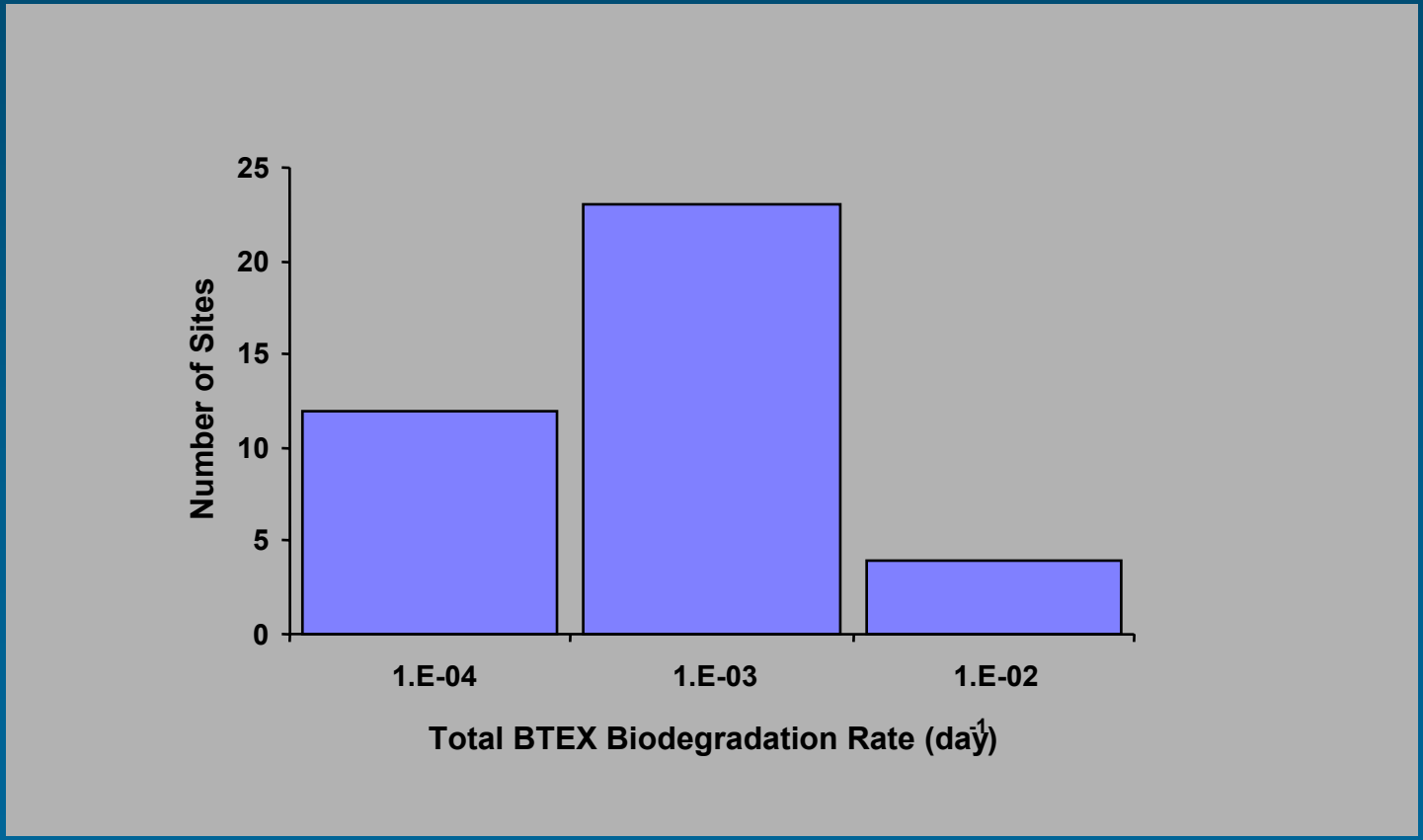
(Excluding 5 Sites with >200mg/l Sulfate Reduction Capacity)



Treatability Study Results (continued)

- **The total BTEX assimilative capacity of groundwater averaged 64 milligrams per liter.**
- **The field-scale biodegradation rate constants ranged from 0.0002 to 0.08 percent per day (day^{-1}), with a geometric mean value of 0.0019 day^{-1}. Or, biodegradation half-lives of 9.5 years to 9 days, with a mean half-life of 1 year.**

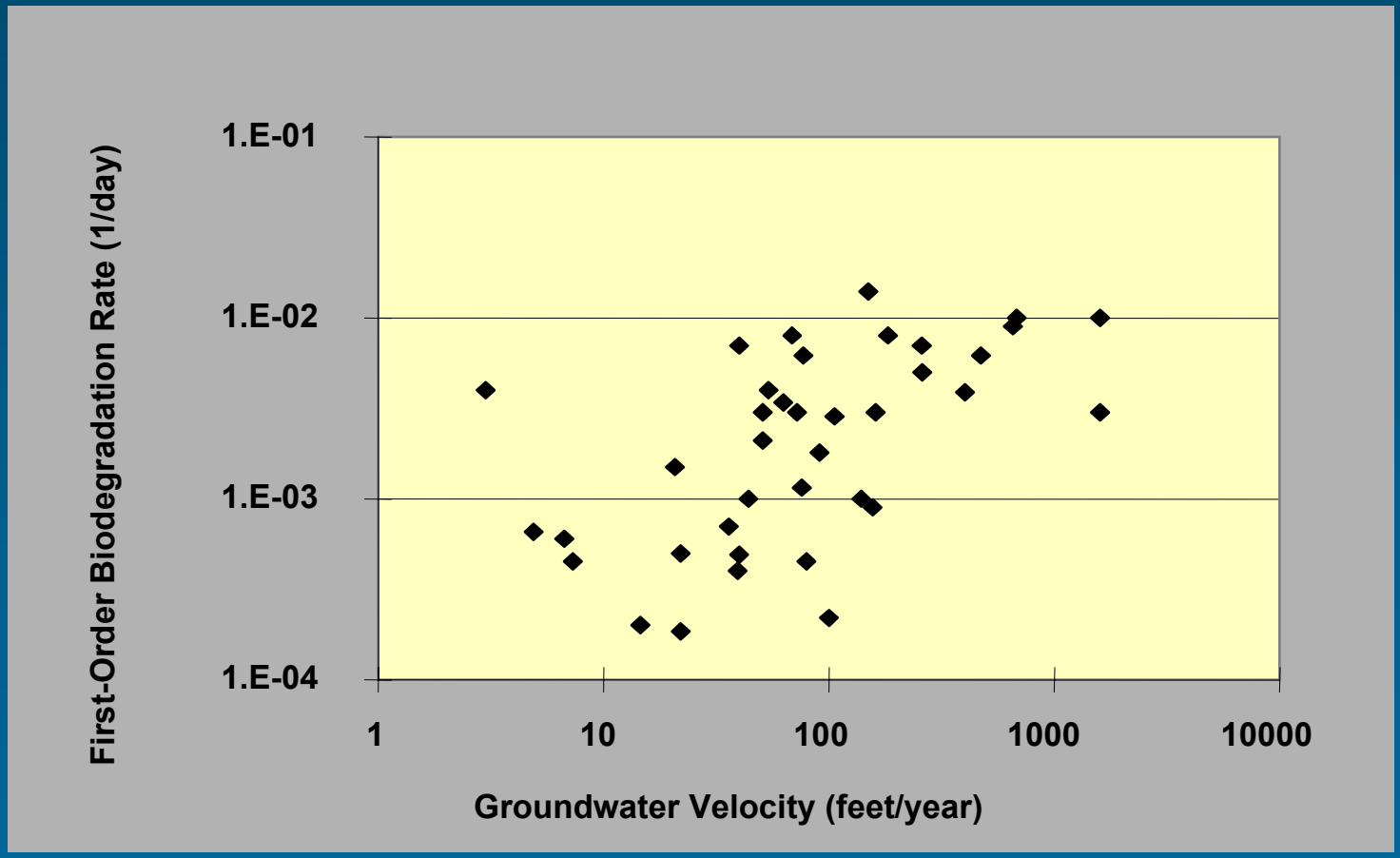
Estimated BTEX Biodegradation Rates



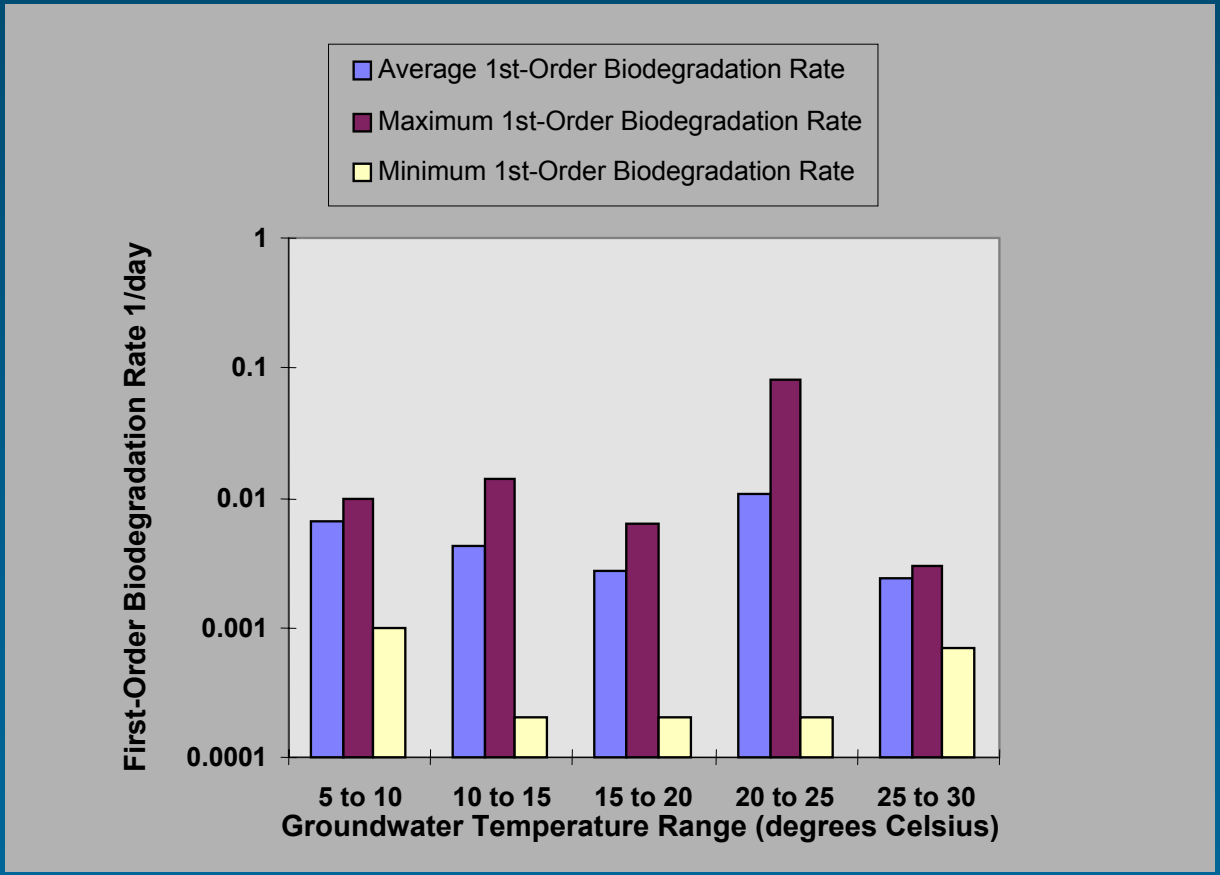
Treatability Study Results (continued)

- **There was some correlation between field biodegradation rates and groundwater velocity; correlation between biodegradation rates and groundwater temperature, assimilative capacity, and plume length were not apparent.**

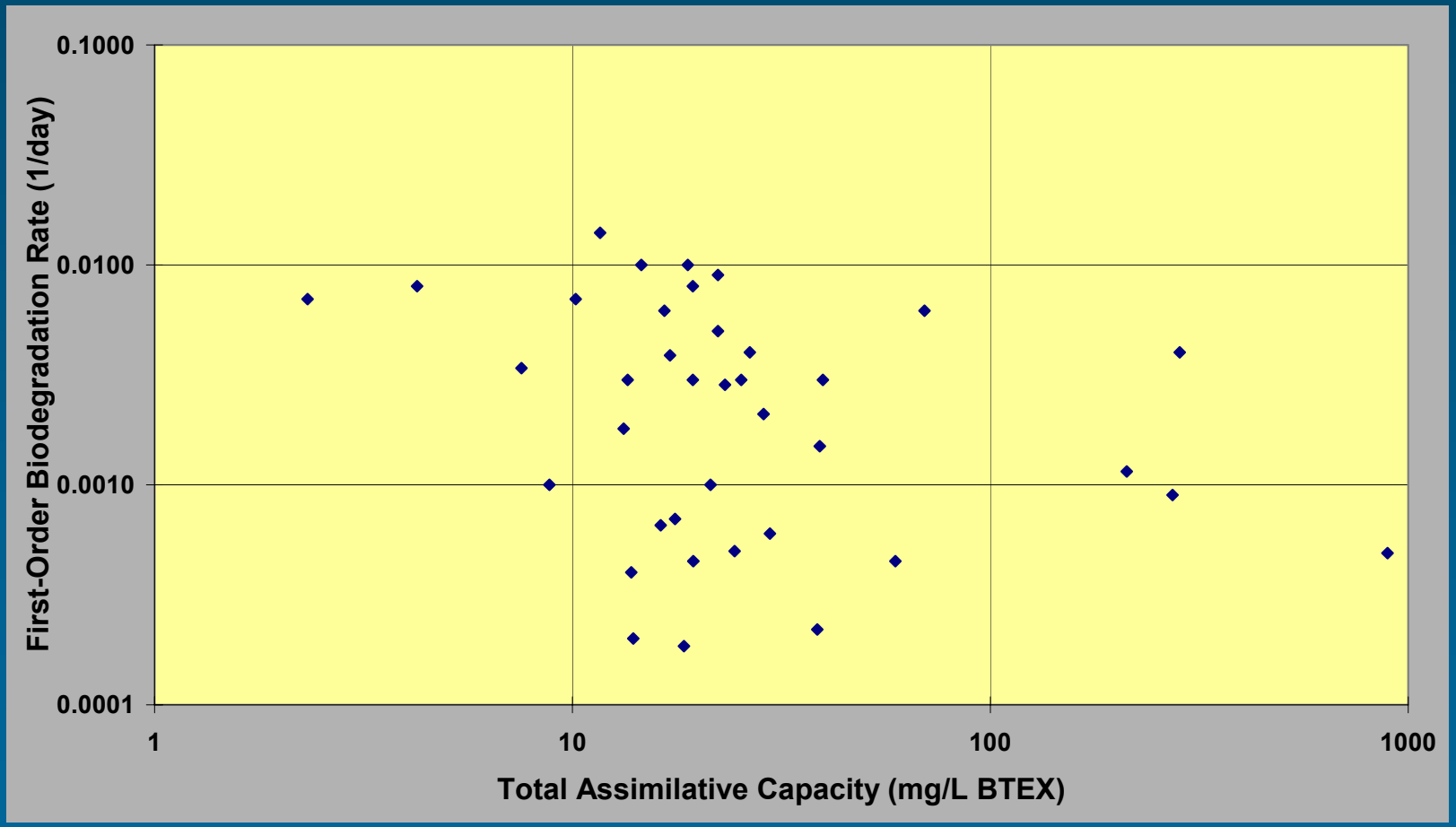
Biodegradation Rate versus Groundwater Velocity



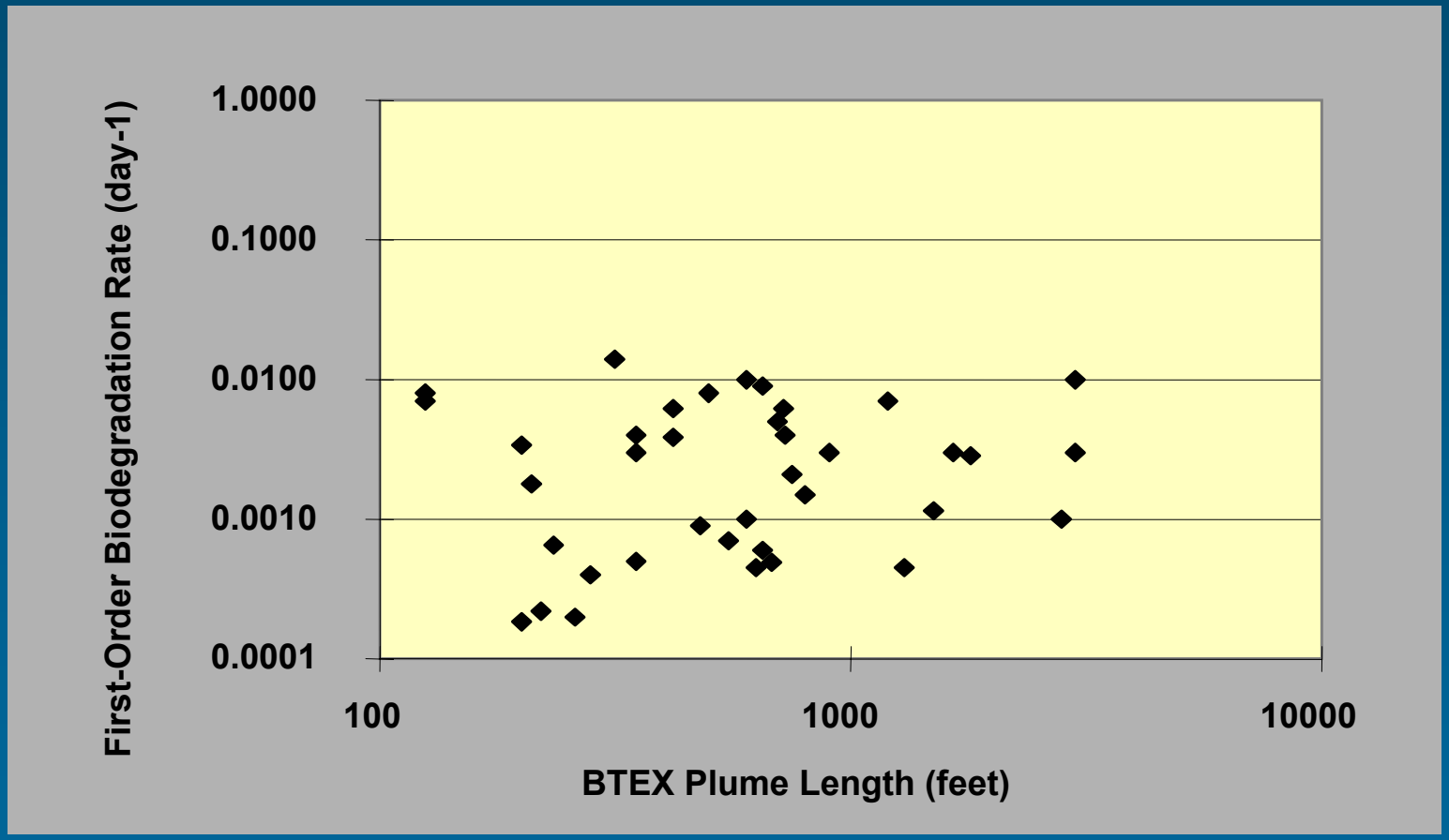
First-Order Biodegradation Rate versus Groundwater Temperature



Biodegradation Rate versus Total Assimilative Capacity



First-Order Biodegradation Rate versus BTEX Plume Length



Are these correlations, or lack thereof, significant?

- **Biodegradation of BTEX compounds was documented under ALL environmental conditions encountered.**
- **Biodegradation, in conjunction with the non-destructive mechanisms of natural attenuation (advection, dispersion, and sorption), was significant enough to stabilize or attenuate groundwater plumes at the majority of sites.**

Treatability Study Results (continued)

- **The average predicted time frame for dissolved BTEX to naturally attenuate below regulatory cleanup standards is conservatively estimated at 30 years. Engineered source reduction typically is required to attain cleanup standards in less than 20 years.**

Treatability Study Results (continued)

- **The average cost per site for completing Geoprobe® site characterization, laboratory analysis, data analysis, fate and transport modeling, and reporting was $126,000. Slightly higher costs (up to $136,000) were incurred at sites where conventional auger drilling was required due to groundwater depth.**

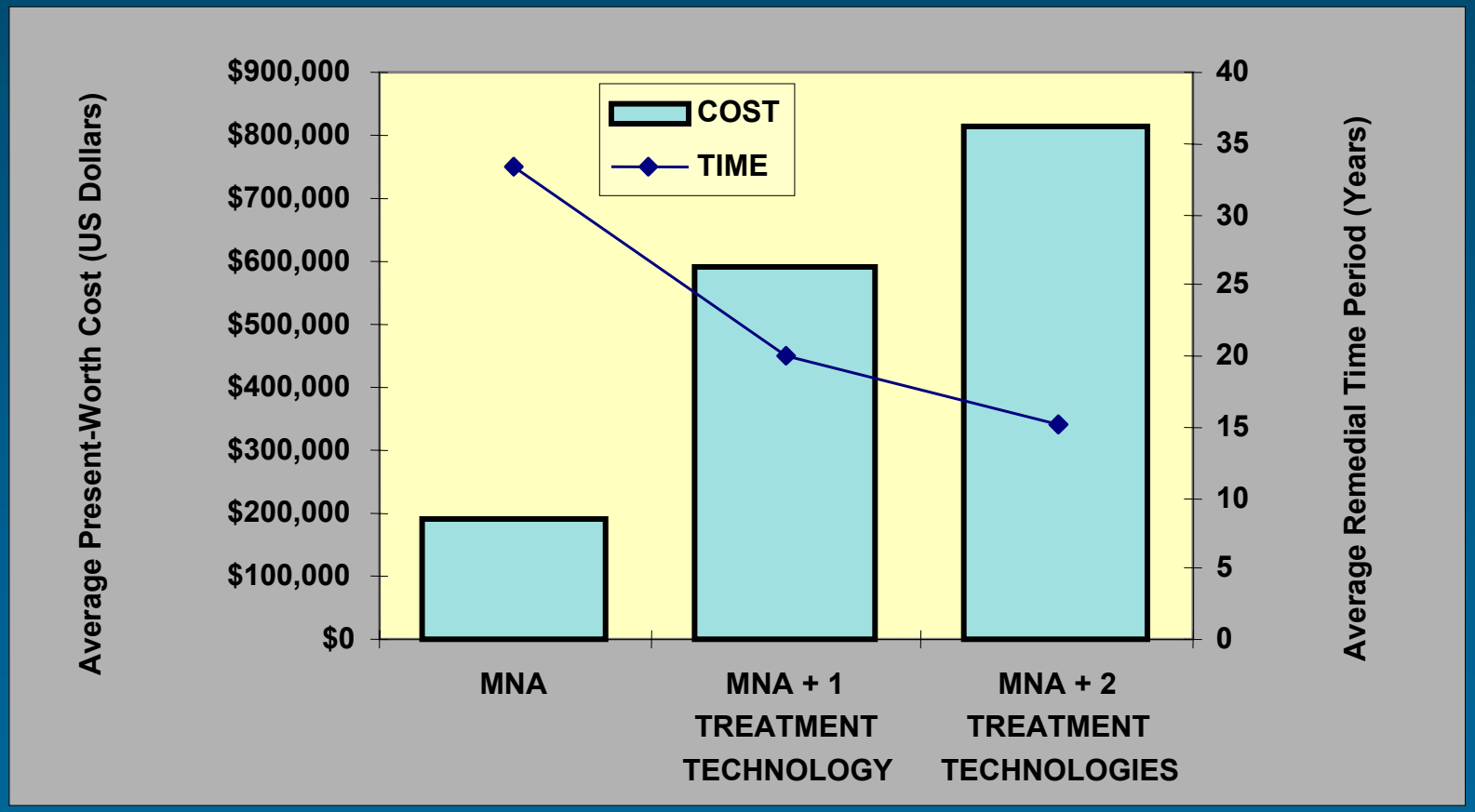
Typical Natural Attenuation Treatability Study Costs

Task	Hollow-Stem Auger	CPT	Geoprobe®
Site Visit/Technical Support	$ 9,960	$ 9,690	$ 9,690
Work Plan/Regulatory Approval	$19,300	$19,300	$19,300
Field Work Labor	$13,900	$13,900	$13,900
Field Work ODCs			
• Survey/Supplies/Per Diem	$ 9,150	$ 9,150	$ 9,150
• Drilling	$12,800	$11,500	$ 2,300
• Data Analysis/Analytical	$15,300	$15,300	$15,300
Modeling	$15,000	$15,000	$15,000
Treatability Study Report	$40,500	$40,500	$40,500
Total Project:	**$136,000**	**$134,000**	**$126,000**

Treatability Study Results (concluded)

- **Recommended LTM programs for MNA included an average network of 11 wells with a duration of 22 years, and had an average total program cost of $192,000.**
- **At many sites, natural attenuation processes had stabilized the groundwater plume, but engineered source remediation was recommended to reduce the duration and cost of LTM.**

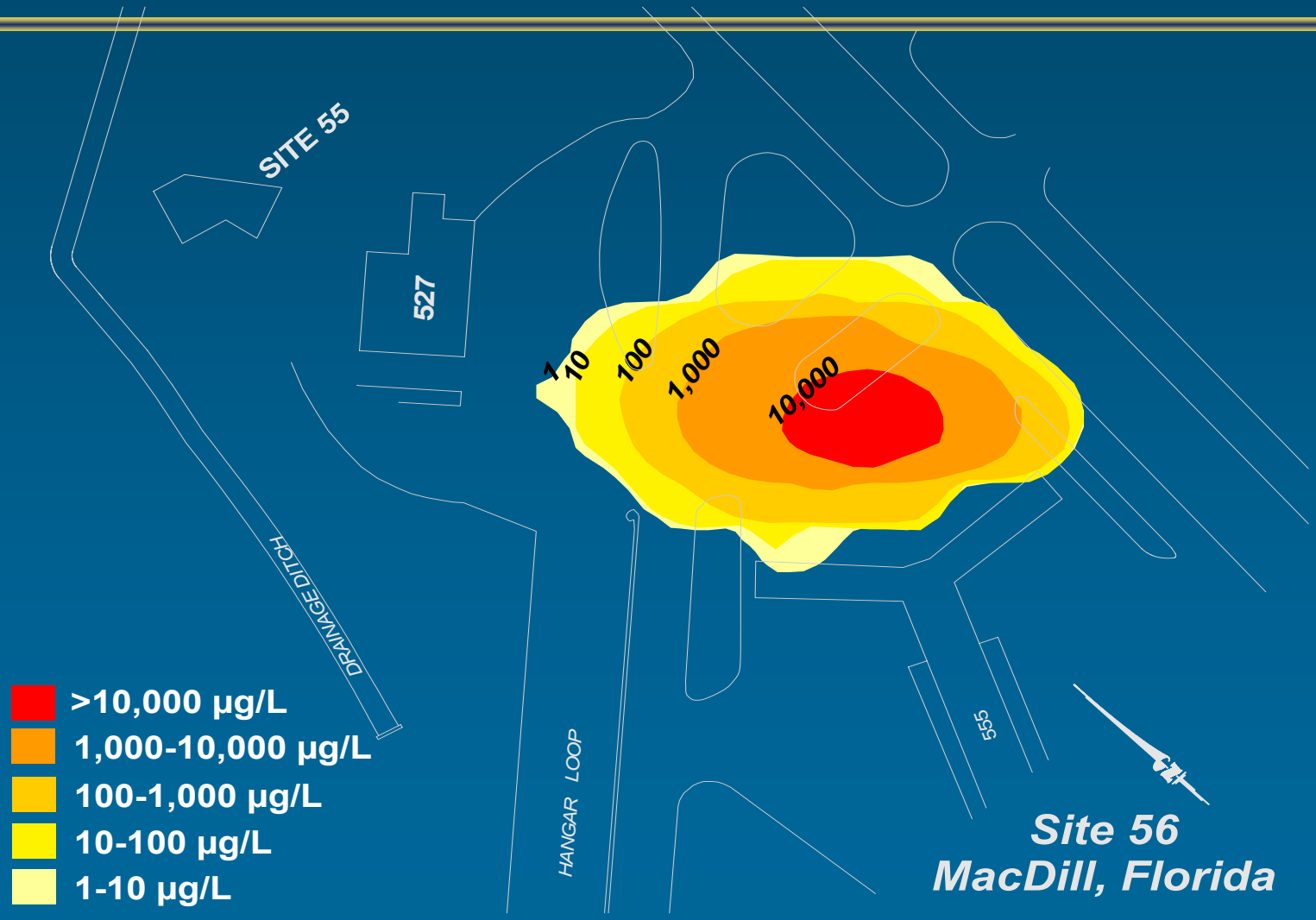
Time and Cost Relationship for Remedial Alternatives



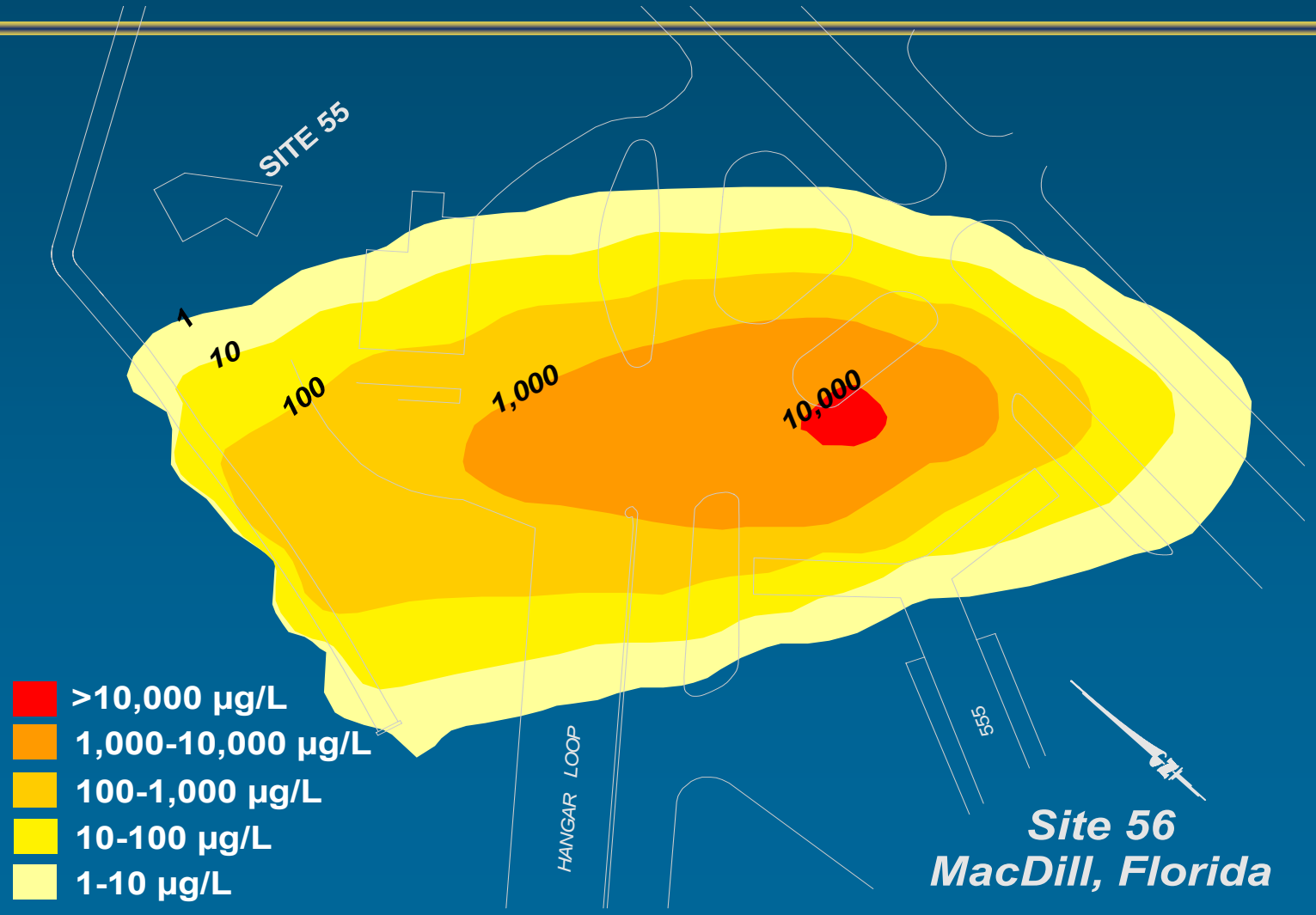
Case Study: MacDill AFB Service Station Site 56

Service Station Fuel Release Site

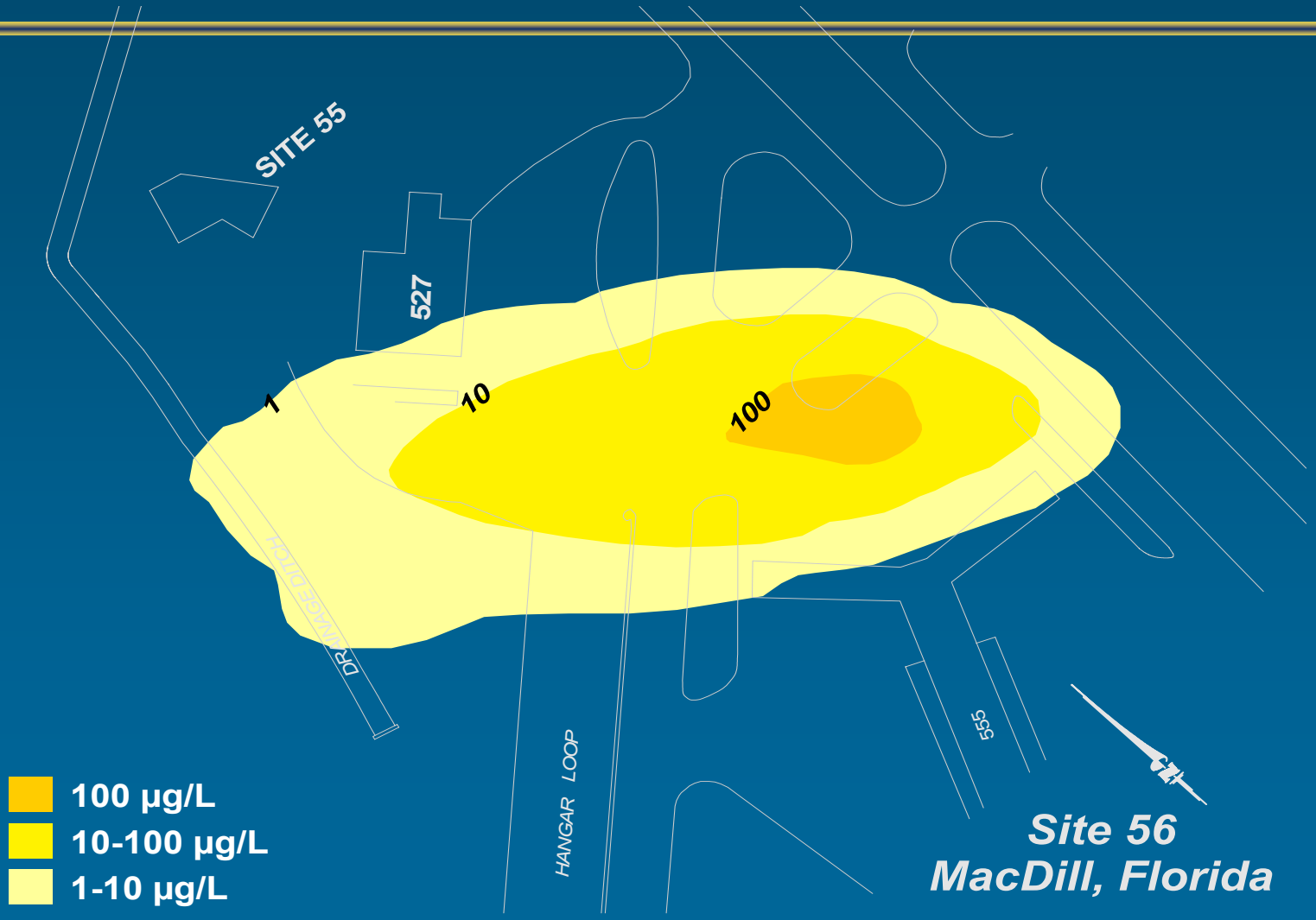
Calibrated Total BTEX Plume



Simulated Total BTEX at 10 Years



Simulated Total BTEX at 50 Years



Site 56 Remedial Alternatives

- 1. RNA with LTM and Institutional Controls
  - BTEX in GW > RAO for 50 years
  - BTEX in SW may exceed RAO
  - Present worth cost $250,000
- 2. RNA/LTM + Bioventing/SVE
  - BTEX in GW > RAO for 10 years
  - BTEX at ditch reduced by 1/2
  - Present worth cost $348,000

Site 56 Remedial Alternatives (continued)

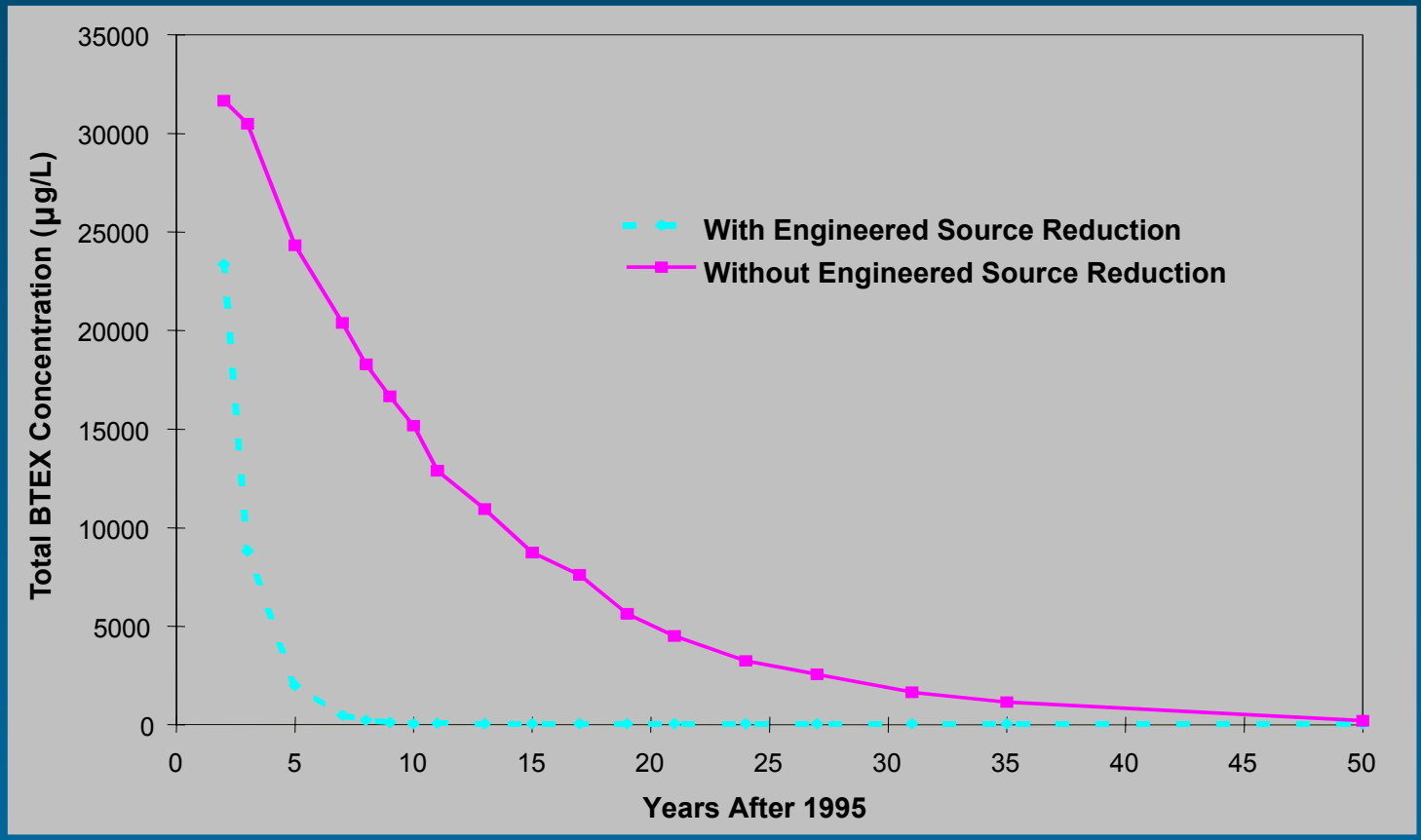
3. Same as Alt. 2 + Limited GW Extraction

- BTEX in GW > RAO for 6 years
- Present worth cost $486,000

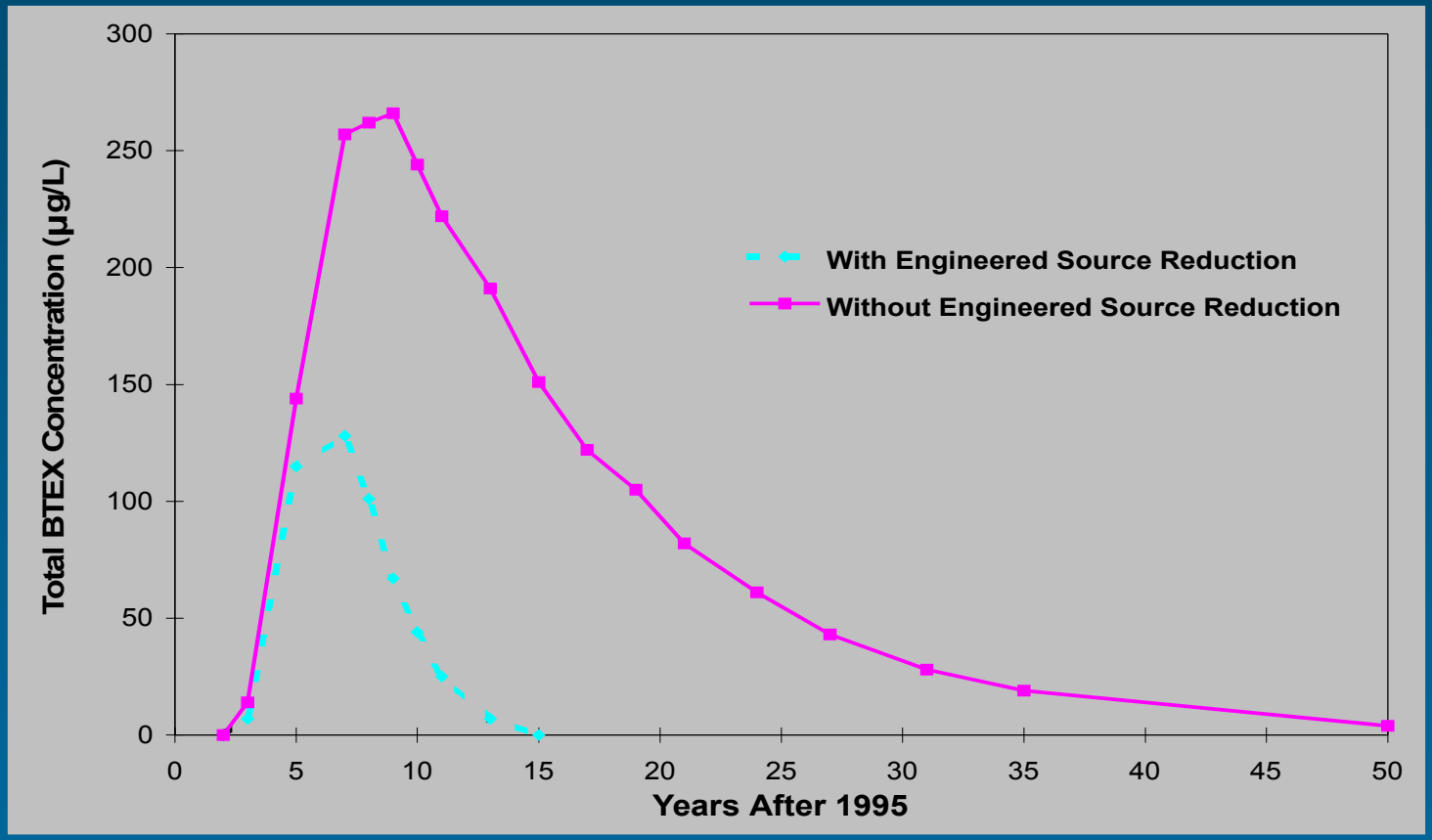
4. RNA/LTM + Soil Excavation

- Same effects as Alternative 2
- Suitable if station closes
- Present worth cost $333,000

Comparison of Simulated BTEX Concentrations at Source Area



Comparison of Simulated BTEX Concentrations at Drainage Ditch



Summary of Remedial Alternatives

Remedial Alternative	Time Frame to Remediation	Present Worth Cost Estimate
Alternative 1		
- Intrinsic Remediation - Long-Term Monitoring - Institutional Controls	Long-Term Monitoring - 50 years	**$250,000**
Alternative 2		
- Bioventing/Biosparging - Soil Vapor Extraction (SVE) - Intrinsic Remediation - Long-Term Monitoring - Institutional Controls	Active Remediation - 3 years. Long-Term Monitoring - 14 years	**$348,000**
Alternative 3		**$486,000**
- Groundwater Extraction - Bioventing/Biosparging - Intrinsic Remediation - Long-Term Monitoring	Active Remediation - 3 years Long-Term Monitoring - 10 years	
Alternative 4		**$333,000**
- Soil Excavation - Intrinsic Remediation - Long-Term Monitoring	Active Remediation - 3 months Long-Term Monitoring - 14 years	

Site 56 Recommendations

- **Alternative 2 achieves best combination of risk reduction and cost effectiveness**
- **If station closes, Alternative 4 may be most appropriate**

Lessons Learned:

- **Natural attenuation with biodegradation of fuel hydrocarbons is ubiquitous throughout the environment.**
- **Natural attenuation rates were rapid enough to stabilize hydrocarbon plume migration even when groundwater velocities were relatively high.**
- **Evaluate natural attenuation as a preferred remedy for fuel-contaminated groundwater before considering other more costly alternatives.**

Lessons Learned (continued):

- **In cases where engineered remediation is required to lessen the remediation time frame or to protect potential receptors, low-cost, *in situ* source reduction (e.g., bioventing, SVE, and biosparging) should be considered to speed the remediation process.**
- **More costly remediation techniques (e.g., groundwater extraction and treatment) should be implemented only if the plume poses an imminent threat to human health or the environment.**

Lessons Learned (continued):

- **Important factors to consider when using MNA are the required level of groundwater modeling and the potential value of source reduction technologies in reducing LTM time frames and obtaining regulatory acceptance of a site closure strategy.**

Lessons Learned (concluded):

- **AFCEE/ERT and Parsons ES have implemented a streamlined risk-based site closure program that incorporates the "lessons learned" from natural attenuation studies.**
- **Under this program, fuel-contaminated sites are obtaining MNA site closure agreements at half the cost of the original natural attenuation TSs.**

Special Considerations:

- **With the majority of fuel hydrocarbon plumes either stable or receding, the focus of site remediation shifts to the persistence of contaminants in groundwater at levels above regulatory guidelines.**
- **Several states have published guidance or regulations regarding the conduct of natural attenuation studies.**
- **Some regulatory agencies may have restrictions on the time frame for remediation by natural attenuation (e.g., State of Florida - 5 years)**

Special Considerations (concluded):

- **Property transfer or sale may impose time constraints on remediation (base closures, real estate sales).**
- **Responsible parties are subject to continuing environmental liability during the long-term remediation.**
- **No guarantees that regulatory guidelines will not change in the future (e.g., time frame to remediate, possible enforceable guidelines for MTBE).**